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The performance analysis dependent on temperature for EDFAS pumped at 1480 nm pump wavelength: a theoretical investigation

Cüneyt Berkdemir (OSA Member) and Sedat Özsoy

Department of Physics, Faculty of Arts and Sciences, Erciyes University, Kayseri, Turkey, 38039, berkdemir@erciyes.edu.tr and ozsoys@erciyes.edu.tr

Abstract

The effect of temperature on the population distribution within the manifold of an Er^{3+}-ion pumped at 1480 nm pump wavelength is theoretically investigated. A modified rate equation model for determining the signal gain performance of EDFAs is established by including the temperature effect and the gain values versus launched pump powers at the temperature range of – 20 to 60 ^{o}C are obtained under the signal power regime.

Summary

1- Introduction

The operational properties of erbium-doped fiber amplifiers (EDFAs), which have an important role in optical fiber communication systems operating at the 1.55 μm window, directly depend on the pump and signal characteristics. It is well-known that an erbium-doped fiber amplifier demonstrates the property of two-level amplification system when it is pumped at 1480 nm wavelength [1]. Particularly, the distribution of Er^{3+}-ions within the metastable level ($^4I_{13/2}$) changes continuously with temperature according to Boltzmann's distribution law, owing to the closeness of the pump and signal rates within this level. Thus, the population of metastable level shows a highly temperature sensitive signal gain for 1480 nm pumping regime [2, 3]. In this study, we analyzed theoretically the signal gain performance of EDFAs pumped at 1480 nm pump wavelength by using the temperature-sensitive rate equation model in the practical temperature range of – 20 to 60 $^{o}\mathrm{C}$.

2- Modified Rate Equation Model

The solution of the two-level amplification system can be carried out by using the modified rate equations in terms of the pump absorption and emission rates (R_{1-22} and R_{22-1}, respectively), the signal absorption and emission rates (S_{1-21} and S_{21-1}, respectively) and the amplified spontaneous emission rate γ_{sp}. Then, an expression for the relative populations in the metastable level, N_2 / N, at steady state conditions is found as

$$\frac{\mathrm{N}_2}{\mathrm{N}} = (1+\beta)\frac{\mathrm{I_p}\sigma_{1-22}\mathrm{P_p} + \mathrm{I_S}\sigma_{1-21}\mathrm{P_s}}{\mathrm{I_p}((1+\beta)\sigma_{1-22} + \beta\sigma_{22-1})\mathrm{P_p} + \mathrm{I_s}(1+\beta+\eta)\sigma_{1-21}\mathrm{P_s} + 1}, \quad (1)$$

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where $I_p = \Gamma_p \tau / h\nu_p A_{eff}$, $I_s = \Gamma_s \tau / h\nu_s A_{eff}$; ν_p and ν_s are the pump and signal frequencies, respectively; *h* is Planck's constant; τ is the lifetime of metastable level; Γ_p and Γ_s are the pump and signal overlap factors, respectively; A_{eff} is the effective core area. The relevant parameters used in Eq.(1) are as bellows: σ_{1-22} and σ_{22-1} are the stimulated absorption and emission cross sections for the pump wavelength, while σ_{1-21} and σ_{21-1} are for the signal wavelength; $\eta = \sigma_{21-1}/\sigma_{1-21}$ (from McCumber's theory). P_p and P_s are the pump and signal powers, respectively. The parameter β in Eq.(1) is characterized by the Boltzmann's distribution of Er^{3+}-ions within the $^4I_{13/2}$ energy state and given by $\beta = N_{22}/N_{21} = exp(-\Delta E_2/k_B T)$. k_B is the Boltzmann's constant, $\Delta E_2 = E_{22} - E_{21}$ is the energy difference between the sublevels N_{22} and N_{21} and its value is nearly 200 cm^{-1} at temperature range of -20 to 60 ^oC. The gain parameter $G(\lambda_s)$ is defined by $G(\lambda_s) = e^{\gamma.L}$, where $\gamma = \sigma_{1-21}(\eta N_2 - N_1)\Gamma$, γ is small-signal gain coefficient and L is the doped fiber length.

Results and Discussions

Using EDFA parameters given in Table 1, we have plotted the dependence of gain on the launched pump powers at temperature values of -20 ^oC , 20 ^oC and 60 ^oC in Fig.1.

Table 1. EDFA parameters used for the calculations.

σ_{1-22} (10^{-25} m^2)	σ_{22-1} (10^{-25} m^2)	σ_{1-21} (10^{-25} m^2)	σ_{21-1} (10^{-25} m^2)	$\Gamma_p ; \Gamma_s$	A_{eff} (10^{-12} m^2)	*N* (10^{23} m^{-3})
1,86	0,42	2,85	5,03	0,43; 0,37	12,6	9,28

The value of $\sigma_{21-1}/\sigma_{1-21}$ at room temperature (20 ^oC) for 1550 *nm* signal wavelength is obtained as 1.76, because there is a relationship between signal emission and absorption cross sections in the form of $\eta = exp\left[hc / k_B T(1/\lambda_0 - 1/\lambda_s)\right]$ according to McCumber's theory. The wavelength λ_0 depends on the electronic structure of the ground and the excited state of the Er^{3+}-ion and its value is calculated as 1522, 7 nm. Thus, the values of η at – 20 and 60 ^oC are 1.93 and 1.65 and also the values of β at – 20, 20 and 60 ^oC are calculated as 0.33, 0.38, 0.43, respectively.

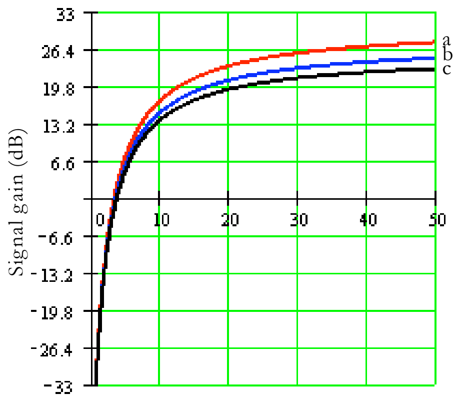

Fig. 1. The variation of signal gains versus launched pomp powers for the signal power regime 50 μW. (a), (b) and (c) curves correspond to – 20 °C, 20 °C and 60 °C, respectively. τ is taken as 10 ms and $L = 15\,m$.

Fig. 1 shows in 50 μW signal power regime that, the gain values increase an amount of 3-5 dB when the temperature is decreased from 60 °C to -20 °C. Thus, it is seen from the gain analysis that the performance of EDFAs pumped at 1480 nm pump wavelength is affected by the temperature. In addition, it is seen from the modified rate equation (Eq.1) that the smaller signal powers are more efficient than the higher signal powers. Moreover, this model which involves β and η is more accurate to describe the signal gain for a wide range of temperatures for EDFAs pumped at 1480 nm pump wavelength.

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References

1. E. Desurvire, Erbium-doped fiber amplifiers: principles and applications, John Wiley & Sons, New York, 1994.
2. M. Suyama, R. I. Laming, and D. N. Payne, Temperature variation of gain in a 1480 nm-pumped erbium-doped fiber amplifier, Proc. Optical Amplifiers and Their Applications, Monterey, 1990, WD3.
3. C. Berkdemir and S. Özsoy, An investigation on the temperature dependence of the relative population inversion and the gain in EDFAs by the modified rate equations, Optics Communications, in Press, (2005).